

Tolerance deviations of the exhaust system regarding to template manufacturing errors with application of 6-Sigma

Filipe Queiroz Soares Ferreira, Matheus Stephen Nascimento e Chaves, Raphael Ramos Magalhães

Salvador University, UNIFACS, Salvador, BA, Brazil.

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Abstract— This article aims to explain the negative impact of tolerance deviations in exhaust systems due to template manufacturing errors. It also attempts to present the application of Six sigma as a solution for the issue since it helps to correct those errors of the templates. Six Sigma is a quality management methodology, that when applied correctly, helps to achieve greater standardization, which in turn improves the quality of exhaust system. It also ends up positively impacting work culture and increasing customer satisfaction. The article is based on the comparison between estimated productivity and estimated losses. Due to confidentiality reasons all data was estimated. The research also focused on 6-Sigma solution method for the automotive industry. The results obtained proved the benefits of the application of Six Sigma.

I. INTRODUCTION

The exhaust system is responsible for part of the engine's performance, reduction of the greenhouse effect attack and noise generated. Because of that, the automotive industries are increasingly seeking and developing new components, so that their functions are improved in terms of market and cost-benefit. According to CHOLLET (2002), for the components to perform their functions as designed, it is necessary that during its assembly and manufacture there are no deviations above the acceptable, as they would negatively affect the vehicle set. To ensure deviations within an acceptable limit, quality tools are used that aim at standardization, organization, discipline, cleanliness, the correct selection of materials and the employee's safety during assembly. Although, according to Sachin (2017), global competitiveness is making the manufacturing industries going through a tough challenge to produce high quality and customized products at low cost to meet the rocketing market demand.

Directing the combustion gases from inside the engine to a location away from it, is one of the functions that aim to remove, as much as possible, all combustion products from the cylinder after the explosion in the most efficient way possible. As noise is a comfort item and needs to be attended to reduce noise pollution, the exhaust reduces the noise caused by the engine, through mufflers, reducing from 125 dB to 50 dB and also reduces the amount of toxic pollutants that are emitted into the atmosphere, thanks to the catalyst, which promotes the oxidation of carbon monoxide and hydrocarbons, the reduction of nitrogen oxide, causing oxygen, nitrogen, carbon dioxide and water to be eliminated by the exhaust.

The engine power is directly influenced by the exhaust system, because by increasing the amount of air sucked into the cylinder during intake, the movement of combustion gases through the exhaust system causes a suction effect in the intake of fuel air, achieving high values of volumetric efficiency, thus resulting in higher powers.

The manufacturing of the exhaust system is directly connected to the conditions of the template. Yet, the template is a guide for the curvature and alignment of the exhaust pipe when being welded to the other components of the system. The operator uses the template to follow the calculated drawings to achieve greater process efficiency and avoid interference with other parts of the vehicle. “6-Sigma” is one of the most used quality management methodologies in the industrial branch due to its high efficiency and ease of application in the process and implementation in the workforce. “6-Sigma” aims at the improvement and inspection from the beginning to the end of the process and in all stages and connections to it.

This way, the exhaust system is of great importance to the automobile industry and demonstrates direct interconnection in other parts of aesthetics, such as bumpers, chassis and clamps. A problem in any of these components affects all nearby areas, producing a “chain reaction” effect. For this reason, the work aims to achieve improvements in performance, ergonomics, practicality and implantation of design and assembly patterns of the exhaust system, by using the “6-Sigma” quality management methodology.

II. THEORETICAL FOUNDATION

Welding process

According to MACHADO (1996) “Welding is one of the oldest joining, coating or maintenance processes in industry. In the end of the 19th century, elements and objects of same or different materials, were joined together by depositing a heated component, called welding”. The welding process is applied in the foundry, machinery and metallurgy industries and has several ways and methods of joining two materials.

- **Metal Inert Gas (MIG) Welding**

According to OKUMURA (1992) “The MIG welding type is an electric arc process between the part and the uncoated electrode, called welding wire. The electric arc joints the wire in the base metal, forming a fusion puddle that has a gaseous protection by an inert gas like Argon or Helium that prevents gases from the atmosphere from penetrating the weld, causing oxidation or damaging it, for example”.

The advantage of this type of welding is that it can be done in all positions, regardless of the angle. It is a semiautomatic process, which both man and machine can perform- it is easy to operate, it has low production costs and its components have high deposition rate of weld metal, high welding speed, short time, good finish and excellent

weld quality, therefore, widely used, mainly in the automobile industry.

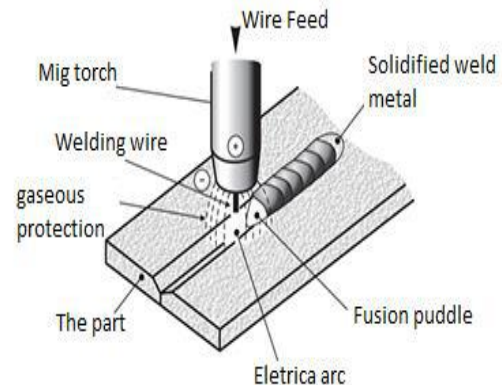


Fig.1: Detailing of the MIG welding application.

Source –ESAB, 2014.

- **Exhaust System Welding**

According to CHOLLET (2008) “The exhaust system consists of several components such as exhaust manifolds, catalytic converter, silencer, muffler, discharge pipe and the connection pipes. In order to interconnect these parts, they need to be welded in a correct and standardized way, so that the functionalities of the components are preserved with quality and safety”.

The beginning of the welding process of the exhaust tubes is based on the technical drawings of assembly and the fixation of the components on clamps and jigs. Clamps and jigs serve as manufacturing guides so that, after two pre-steps, objects interconnected are welded by welding in point. If the position, angle, or alignment are incorrect, there is chance to correct them before welding, since points are used just as a guidance.



Fig.2: Continuous welding of exhaust system pipe.

Source – FERREIRA, 2014

In the next step, the positions of the points as well as the alignment of the system are checked and compared to the technical drawing. If the tolerance deviations are within

the acceptable range and do not compromise the use of the exhaust system, continuous welding can be applied in the connection areas between exhaust components. If the tolerance deviation are above acceptable, it can affect car performance, emissions, noise level, vehicle assembly and maintenance in workshops or dealerships.

The continuous welding offers the necessary mechanical and thermal resistance. During its operation there is no leakage or penetration of gases from the atmosphere. Leakage and penetration negatively influence the level of pollutants expelled to the environment and as well as vehicular performance, which an accidental event may occur, leading to damage other vehicles and people, as well as causing vibrations that may generate cracks in the welded points.

Exhaust System Operation

Second BRUNETTI (2012), “The exhaust system does not perform complex tasks. It has a linear construction, where each component (collector, flexible, catalyst, tubes, dampers and mufflers) are assembled in sequence so that each part performs its specific activity for the system”. Basically the exhaust system plays four major functions to improve the performance of an engine:

- **First Exhaust System Function:**

The first and perhaps the most obvious function of the exhaust system is that it was initially developed to direct the combustion gases inside the engine to a location away from the engine. Thus, the exhaust system was designed to remove all combustion products from the cylinder in the most efficient way possible, after the explosion. The better the cleaning of the gases, the better the engine function.

- **Second Exhaust System Function:**

The second function of the exhaust system is to reduce the noise caused by the engine. Currently automobiles such as cars, trucks and even motorcycles are mainly responsible for noise pollution. With the use of silencers in the system, the intensity of the sound coming out of the engine can be reduced by up to 50 dB. Taking into account that the noise emitted by engines can reach 125 dB, reducing it to 50 dB is quite significant.

- **Third Exhaust System Function:**

The third function of the exhaust system is to reduce the amount of toxic pollutants that are released into the atmosphere. The system component that reduces the toxicity of the substances generated by combustion is the catalyst. The catalyst promotes the oxidation of carbon monoxide and hydrocarbons as well as the reduction of nitrogen oxide, causing them to be eliminated by escaping oxygen, nitrogen, carbon dioxide and water.

- **Fourth Exhaust System Function:**

The fourth function of this system directly influences the power produced by the engine. The function is to increase the amount of air drawn into the cylinder during intake. The movement of the combustion gases through the exhaust system causes a suction effect on the intake of the combustible air, achieving high values of volumetric efficiency. This is due to the appearance of negative pressure during the movement of gases through the exhaust. The greater the mass of combustible air admitted to the cylinder, the greater the power of the engine.

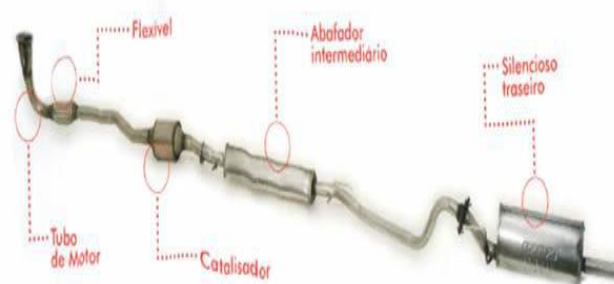


Fig.3: Exhaust System Breakdown

Source – VTN, 2006

Exhaust System Exhaust Process

According to CHOLLET (2002) “The exhaust system process begins with the exhaustion of the gases from the internal combustion engine, where the gases are directed and stored in the exhaust manifold, passing through the exhaust pipes, through the catalyst and then through the gasket flexible, muffler and silencer until released to the environment. In the exhaust manifold, there is an outlet for each of the cylinders that sends these gases to a pipe, in which the exhaust of each cylinder meets.”

After this encounter, this flow passes through a tube that goes into the catalyst, which is the device responsible for the reaction of CO and NO_x with O₂. The gases are transformed into CO₂, N₂ and O₂ respectively.

- **Exhaust System Materials Application**

The exhaust system has a direct relationship with performance, economy and impact on the environment. The exhaust system also reduces the outlet temperature of the gases as well as reduces exhaust gases that are harmful to human health. For example the oxygen sensors called lambda probe acts directly in the engine system performance when activated once the oxygen amount in is above acceptable in the exhaust system, helping the engine reach a better efficiency and reduce the impact on the environment.

The gases resulted from the combustion still need to reduce its temperature and noise resulted from the engine functioning. For this, the gases pass through two devices that absorb all type of frequencies. These devices are called damper and muffler, which respectively play the role of reducing high frequencies, as well as medium and low frequencies.

- **The Importance Usage Of Damper And Muffler For Exhaust System**

The operation of the damper and muffler is identical, as they expand the spaces for the passage of gases. There is a chamber inside the muffler called Helmholtz, which creates an internal resonance and superposition waves. However, it is only actuated when it has greater gas passages usually from high accelerations and larger engines that generate a greater combustion.

Another device, which not all cars have, is the decoupler that reduces vibrations. It is a flexible or spherical joint that reduces vibrations by monitoring the passage of gases after catalysis. The higher the temperature of these gases are, the more it expands the decoupler to prevent leakage and direct the gases along the discharge pipe.



Fig.4: Spherical Joint

Source –

http://www.gknservice.com/typo3temp/fl_realurl_image/vl-i-joint-04-a7.jpg

Exhaust System Legislation and Requirements

The levels of emissions and the structure of the exhaust system are being increasingly targeted and considered as mandatory items to be strictly followed by legislation such as PROCONVE and EURO. The design of the exhaust system is directly related to the car height from the ground, crash test and deformation of the car in crashes. As mentioned previously, the exhaust system transports and filters gases, reduces noise and prevents intrusion of gases. In addition to all those important roles, the exhaust system also should not come into contact with fuel lines or electrical parts, otherwise it would catch on fire.

Six Sigma Methodology

According to ARANTES (2012), "Six Sigma is a set of tools and strategies for improving the process as well as decreasing its variability. Its use improves the process efficiency and generates savings." It also is a highly disciplined and culturally changing management strategy that seeks perfection in processes as well as great productivity. It is a data-based tool, with great commitment to leadership and use of the DMAIC methodology.

The Greek letter σ (Sigma) represents the standard deviation, so the smaller the standard deviation is, the less dispersion of results it will have as well as values closer to the mean and more stable process. This way, it helps to evaluate the quality level, customer dissatisfaction or defect by dispersing results with the aid of Box plot. Six Sigma represents six times the standard deviation, which indicates a process that, according to ECKES (2011), "is a process where only 3.4 defects per million opportunities occur."

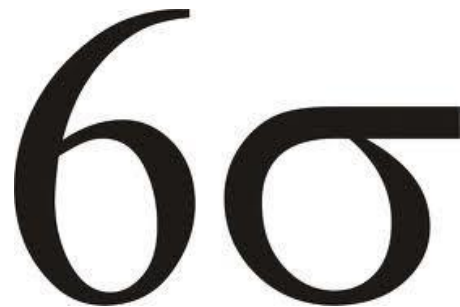


Fig.5: Six Sigma Methodology Symbolology

Source –

<http://api.ning.com/files/5AOnukCMO3WaaXUZMY52mCIA4j97SkMoiQOwjluERevILQooqxzWv-YVfkiyqXi1qQ1mqd6wapo9J1IHVnrzvmr-TvcF0Dxe/sigma.jpg>

DMAIC Methodology

The DMAIC methodology aims to solve problems and improve processes, which is divided into five stages: Define, Measure, Analyze, Improve and Control.

Define:

This stage is responsible for the scope of the project to be worked on, the team, the roles of each of the parties involved and the scope of this project, as well as the schedule and understanding the customers' needs and expectations. According to ECKES (2001), the leadership support on the choice of projects is fundamental to guarantee the human or financial resources of a business, and secure the product development. He also warns about choosing projects that have little impact on the organization's business, so it is necessary to be careful while

choosing which operation to work on and not to deviate from the focus.

In this stage, it is defined the issue to be solve. It includes developing a problem statement as well as identifying objectives, resources and project milestones.

- **Measure:**

In this stage, it involves more numerical studies and data analyses. It is focused on measurement system validation and gathering root causes. The data is measured quantitatively or qualitatively and the indicators will have a positive impact at the end of the project and it is of great importance in determining the current performance of the process. As the major difference between Six Sigma and the other methodologies is the validation of improvement, the entire process is based on data to point out trends and concrete values of the process.

It takes knowledge in statistics to demonstrate only what is necessary to obtain reliable means of measuring the process through its variables. It is highly needed to validate the reliability of the obtained results to have meaningful conclusions that lead to the correct path and avoid any kind of rework or loss of time.

When defining- what is measured, ensuring reliable means of measurement, determining the results obtained and validating the data- the next step is the data collection plan that according to ECKES (2001) and WERCKEMA (2012) consists of:

- What to measure: What kind of processes need to be measured to solve the problem in question?;
- Measurement Type: What will be measured in this process? The results, the inputs, the process itself or its time?;
- Data type: Continuous data (measurements, time, weight) or discrete (Yes / No, Good / Bad);
- Operational definition: The end and the beginning of the measurement. It is important to standardize measurements using the same collected database;
- Data collection form: It depends on the type of data to be measured. It can be a control chart, verification sheets or any other form that is more suitable for the type of data to be measured;
- Sampling: Define the amount of data to be measured, such as a batch.

For greater focus on the problem, statistical tools such as Pareto graph and Histograms are used.

- **Analyze:**

In this stage, the true causes of the problem will be discovered. For each of the goals, the analysis phase must indicate an answer as a solution. According to ECKES (2001) and WERCKEMA (2012), the objective of the analysis phase is to examine the data taken in the "Measure" phase and from that stage, find the source of the problem.

The combination of data analysis and process investigation to identify the root cause of the problem is what makes Six Sigma's analytical power quite efficient. In the analysis phase, statistical analysis tools common in the Measure phase are used, such as: histograms and Pareto diagrams. According to ECKES (2001), the participation of the whole team is fundamental in this process because it aims to find the root cause of the problem and this flows better through brainstorming.

The tool that is most used in the Analysis phase is the Ishikawa Diagram, also known as Fishbone Diagram or Cause and Effect Diagram. This tool is very efficient, it uses brainstorming based on these questions "what, where, how and why", as a way to find the root cause of problems through the Cause and Effect Diagram. With that, the possible root causes or effects are directly related to the problem as shown in the figure below.

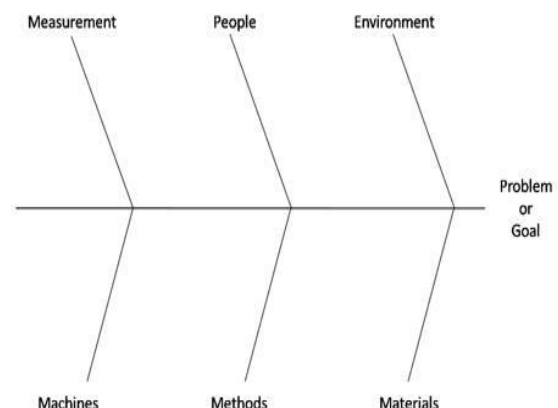


Fig.6: Fishbone Diagram

Source: <https://www.spcforexcel.com/spc-blog/what-cause-and-effect-fishbone-diagram>

ECKES (2001) divides the Analysis Phase into three stages:

- Openness: generally all the chances of causes are raised by brainstorming;
- Bottleneck: prioritization of causes and clarification of ideas to reduce the number of possible causes;
- Closing: Where the real cause of the problem is identified based on the data. The analysis can often point to several causes, which makes it difficult to

make a decision as to which cause would be the most relevant and which should be attacked.

- **Improve**

After defining, measuring and analyzing the root causes of the problem as well as reaching a conclusion, there is a need to raise hypotheses for the improvement phase. Some fundamental questions should be asked at this stage, for instance:

"What possible actions or ideas help to address the root cause of the problem and achieve the desired goal?"

"What possible ideas form solutions with viable potentials?"

"Which solution is most likely to achieve the goal with the least problem and cost?"

"How will the chosen solution be tested to confirm its effectiveness and subsequent implantation?"

In order to prioritize matrices, brainstorm or even by applying trial and error, one should start from a wide group of possible solutions, choosing the ones that bring the best benefit, taking into account the possible improvements in other processes. The choice of solutions must take into account the execution time, resources used, ergonomic and safety impacts as well as any other necessary factor. There is a need to create plans for deploying process improvement. According to ECKES (2001), three crucial factors stand out in the implementation of a solution:

1. Planning: A consistent plan is essential to implement the plan, avoid unforeseen events and motivate the team;
2. Piloting: Experimenting with solutions on a smaller scale is essential to avoid wasting resources on solutions that will not bring good results;
3. Problem Prevention: Always predict the worst case.

According to WERCKEMA (2012), after the execution of the action plan, the next step will depend on the achievement or not of the idealized goal. If the result was positive, the next step is to replicate the solution on a large scale. Otherwise, it is possible to review the chosen solution, or even return to the analysis step if it is clear that the cause being attacked was not the root cause of the problem.

- **Control**

The Control phase aims to ensure that maintenance of the performance was achieved by using standard operating procedures that guarantee the uniformity of the activities that are part of the process. Quality audits are especially useful to ensure the efficiency of the

standardization of processes, ensuring the maintenance of results and the permanence of the adopted standard. In addition, it is also necessary to raise awareness through training, use of clear visual language, lectures, meetings and error-proof devices such as sensors, greater supervision and attention to employees.

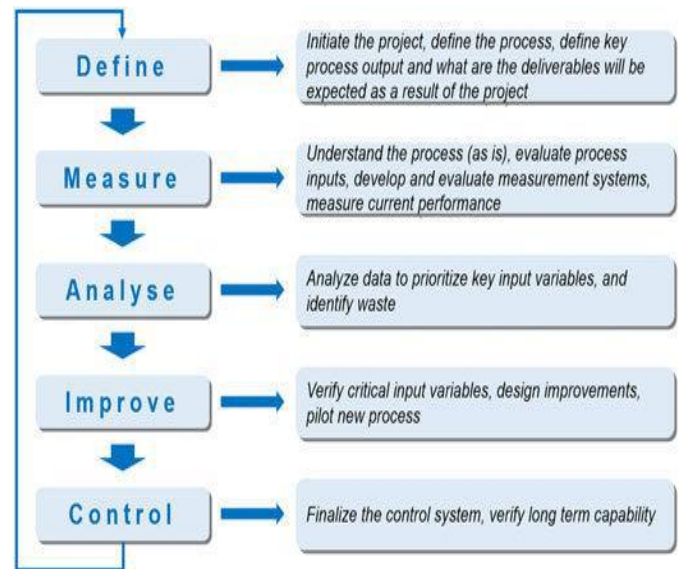


Fig.7: Brief description of the typical lean Six Sigma DMAIC phases.

Source: https://www.researchgate.net/figure/Brief-description-of-the-typical-lean-Six-Sigma-DMAIC-Define-Measure-Analyse-Improve_fig1_32003674020.

Case study

After completing the design project, choosing materials and meeting the emissions and noise requirements, tests were started on the first vehicles. However, some issues were noticed during the manufacture of the exhaust system, and true cause of these issues were unknown. It is not guaranteed that 100% of the lot will be manufactured as planned but there are tolerances due to inherent deviations from the process itself. Those deviations have no effect on the car's performance, level of emissions, noise, risk of accidents or problems on the crash test.

The teams of exhaust system, production, operation, maintenance and quality decided together that the application of Six Sigma would be the best option to solve the problem.

Six Sigma comes to play when a problem is chosen to be improved. In the definition step, it is needed to understand the size of the problem and also measure the

efficiency of the current process. In the measurement step it has to be defined the root cause and also analyze the data in order to finally define a possible improvement in the process at the stage of analysis. After these three initial steps, improvements are implemented and validations of the new process are sought by measuring again the obtained data through Pareto and Ishikawa graphs. It is finally possible to control the implemented improvement when updating documents as well as increasing the security and reliability of the process.

During the definition of the project it was necessary to choose the team members with their respective functions and positions, resources (which could not be informed in financial terms due to confidentiality), as well as the collection of all technical drawings, maintenance reports and also the previous problems in order to finally define what were the possible causes of the problem. Due to confidentiality reasons, all data and information was estimated and focused on 6-Sigma solution Method for the type of issue in the industry.

In this case study it was decided to act on the manufacturing errors of the template for the assembly. The templates for the assembly did not go under maintenance as foreseen by the manufacturer or programmed by the company due to the rush and the need for high batch production. Unfortunately the operators are sometimes not obliged to make it a priority to strictly follow the technical drawings, angles and positions for each of the exhaust pipe components. Thus, certain adaptations usually are made in the templates to accelerate the process and also manufacture the maximum amount as possible of exhaust systems as well as achieving production goals.

To measure the size of the problems found in the batches produced and assembled in the vehicles, the data measuring deviations in alignment and positioning of the exhaust system components were collected as well as the data on how they were produced to then determine the level of process quality. The following conclusion was drawn:

Table 1 –Collected data to evaluate deviations throughout the process.

Production Batch "XY"	Amount of deviations	Beginning of Quality Process	End of Quality Process
Number 1 to 20	1	1	0
Number 21 to 40	5	2	3
Number 41 to 60	12	4	8
Number 61 to 80	20	8	12
Number 81 to 100	29	13	16
Total	67	28	39

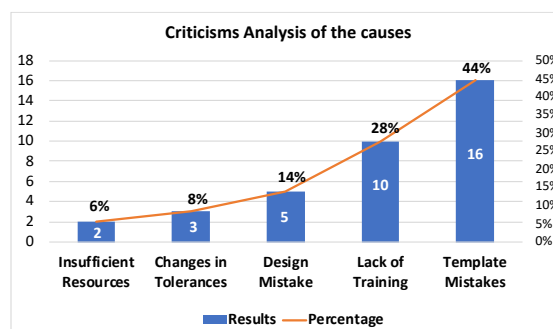
*Acceptable Level: 6 deviations every 100

Source - FERREIRA, 2014

As shown in the table above, the quality level of the products was below acceptable, since the number of deviations exceeds more than ten times the acceptable value throughout the entire process. The use of brainstorming and 5W was also necessary for greater involvement and knowledge of the subject for those involved as well as for a greater chance of finding the possible root cause based on the hypotheses. After the brainstorming and 5W process, the causes could be pointed out through graphics for a later determination of the best solution for the problem in question.

The result of the 5 major critical causes was reached from the analysis of possible root causes and also through the involvement of the team. The following conclusion of the Top 5 was drawn:

Table 2 –Criticism Analysis of the causes using Pareto chart



Source - FERREIRA, 2014

By relying on data, the team determined that the possible root cause of the problems with deviations from tolerances is the template errors. Based on that, the team members began to think of viable solutions that generate profits for the company. This stage of the improvement process is critical, because, from this moment on, it is evaluated whether the solutions will reach the goals established for the company; if it does, it will be applied on a large scale; if it does not, it should return to the previous steps to better assess the causes, think about other hypotheses or even change the type of data collection.

Those involved should ask themselves what actions or ideas would help to solve the problem, which ones would be feasible, which would be the best in terms of simplicity, practicality and cost, and how it will be tested for later validation and permanence of the solution. But it is important to emphasize that this action will not be exclusive for this process but for others too. To this end, action plans are made to determine the consistency of the solution in practice, motivate the team, prevent unforeseen events and the worst situations, as well as small tests for real validation

of actions, before being applied in the process or on a large scale, generating prejudice and loss of time and focus.

Finally, once the improvement action plan has been approved, consolidated and implemented, the last and important stage of Six Sigma will be the control of improvements. The reason to do the control is to ensure that this plan is maintained and followed by the process as well as prevent errors being repeated. The control is made by documentation, rules, supervision, training, use of sensors, continuous action of the maintenance team, operation, design and production by inspecting the manufacture and assembly of the exhaust system and ensuring that Six Sigma is efficient and reliable for the company. It brings quality products at higher levels of satisfaction to the customer, seeking the perfectionism.

Comparison of the templates used to manufacture the exhaust system

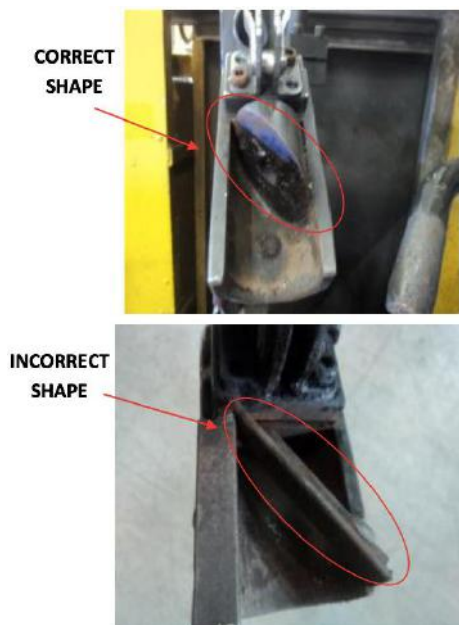


Fig. 8: Difference between correct and incorrect shapes

Source: OTIMAEG, 2013.

The tolerance deviations occurred due to irregularities in the surface of the templates, that are used for the welding and manufacturing processes of the components to the exhaust pipe, as indicated above. As noted, the semi-spherical shape offers the correct curvature to the pipes for better absorption of noise, vibrations and temperature before and after the passages of the components. These components are, for example, catalyst, muffler, silencer and flexible gasket. This type of jig is ideal to meet the requirements and regulated noise and environmental targets as well as the best performance and maximum vibration absorption.

In the incorrect triangular format, the technical design cannot be strictly followed, which compromises all components in their life time. Its positioning and functionality directly impacts the level of polluting gases emitted in the environment as well as the level of noise at the outlet exhaust pipe and the vehicle's power output. It can also cause serious damage to the car, failures during use, leaks or even fires.

Verification of impacts on production and cost, due to the lack of standardization of exhaust systems

The assembly of the exhaust systems, that suffered from deviations of permitted tolerances during their manufacture, causes issues such as loss or stop in production as well as injuries to operators. There were also adaptations to get the exhaust systems fitted in their determined positions on the chassis in order to reach the goals of production levels.

This type of attitude causes malaise in the work environment and a deficit, since the number of vehicles produced in one shift is reduced, their quality as well as an increase in their final cost. These facts occur because of the need to produce the largest quantity in the shortest amount of time to beat the competition. This attitude is not aimed at the satisfaction of employees or the consumer market. That's why it is recommended to use quality tools for solving and maintaining problems.

Implementation of Six Sigma to control and improve the production chain

The change in the company X's attitude when adopting the "6-Sigma" tool will positively impact the production process, satisfaction, control, and, consequently, long-term profit. This tool aims to define what the problem is, how the resolution project will be, what methods are applied to achieve the project design goals, the impact on productivity and the impact on the worker safety. It also requires active control through supervision and progress indicators (in relation to the previous production). Its gains will probably not be seen quickly. However, about two years after its application, the production will certainly show its real impact.

III. OBTAINED RESULTS

It can be seen that the deviation of tolerances is directly related to following the technical welding standards, the design for this and the correct use of the template, which serves as a guide to avoid deviations greater than those of the calculated tolerances. Table 1 shows an estimated comparison of the impact of deviation from tolerances related to what was designed and manufactured,

in relation to the ergonomics of operators on the line, in vehicle losses and productivity.

Table 3 –Comparative between projected and manufactured exhaust system values

Informations	Projected Exhaust System	Manufactured Exhaust System
Tolerance Deviation	$\pm 3.21\text{mm}$	$\pm 4.78\text{mm}$
Cost	\$ -	\$ -
Productivity	97% $\pm 0.8\%$	76% $\pm 2.1\%$
Assembly Losses	Every 1.2 cars per thousand vehicles produced	Every 3.7 cars per thousand vehicles produced
Ergonomics	No fatigue/stress. Operator in ideal position	27 out of every 100 complained of problems related to ergonomics
*Informations taken from vehicle assembly line		

Source – FERREIRA, 2014

As measured in quantitative terms, tolerance deviations result in productivity drop as well as increased losses of resources, profits and labor. Another item that affects the result is the fact that the templates and welding machines were possibly not maintained as planned by the manufacturer or even not programmed by the company. Also, sometimes, the operators are not obliged to strictly follow neither the technical drawings (angles and positions for each of the exhaust pipe components), nor the maintenance plan of the machines.

This way, the evaluation of the reasons for these deviations must be carried out with the aid of Six Sigma, to achieve the greatest number of possible causes of these problems, so that they can be measured, analyzed, implemented and controlled, with the use of training, discipline, cultural change, in order to achieve perfection in processes, validate data and demonstrate it to management for approval or expansion of improvement through quality indicators.

IV. FINAL CONSIDERATIONS

After conducting research based on concepts, applications and features of the exhaust system, jigs, welding processes as well as how the Six Sigma tool could be applied as a way of improving the system, it can be concluded that from an industrial point of view, in a long term, the change results in greater financial profit in sales, client satisfaction, safety and product quality. Although, in a short term, those benefits may not be seen so clearly due to time and cost of implementing the new process.

The exhaust system is a vehicle item of extreme importance not only to obtain cars with better performance but also to reduce environmental impact and noise pollution. Any deviation in its manufacturing process, above what is allowed according to engineering specification, can cause decrease in production, because the

assembly process can suffer from lack of standardization, making it difficult to put the parts of the item together. It affects the employees ergonomics, who will assemble the item in the car or even do its maintenance. All of these also contributes to employees' lack of attention, even forgetting an important item during the assembly process. In other words, it generates a type of "chain reaction", where an error leads to another error, further worsening the situation.

Therefore, supervising, controlling and improving the manufacturing process, modifying and detecting common problems on the template, observing the way technical drawings are being interpreted and applied, verifying what type of welding is being used and also checking the state of the welding machine, provide an improvement in the workforce as well as better rigor and compliance with the norms and standards of the company, resulting in major gains in the long run.

All the facts mentioned above can be explained by the fact that with decrease in production losses, less deviations in equipment tolerance as well as better maintenance and control of activities, generate higher quality and productivity, since the work environment becomes cleaner and more orderly. In addition to that, the employees also adopt a better attitude towards work after the application of Six Sigma. They work more willingly and show greater performances.

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